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BEHAVIOR AND MECHANISM OF COLLOPHANE AND DOLOMITE SEPARATION USING ALKYL HYDROXAMIC ACID AS A FLOTATION COLLECTOR

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Abstract: Flotation response of collophane and dolomite using alkyl hydroxamic acid (AH) (chelating collector) was investigated in the paper. The experiments were performed using pure and artificially mixed minerals as well as a real phosphate ore. Their separation mechanisms were studied by means of zeta potential measurements, infrared analysis, adsorption measurements, thermodynamics, and quantum chemical calculations. The results indicated that AH exhibited an excellent performance in the flotation separation of collophane from dolomite in neutral medium. The P_2O_5 grade of the concentrate increased from 19.84% to 30.51% without any other reagents when the pH value was about 7. The zeta potential and adsorption studies showed that the adsorption of AH at the collophane/aqueous interface was greater than that at dolomite surface, which was the essential reason that separation of collophane from dolomite. The results of Fourier Transform Infrared (FTIR) spectrum and thermodynamics calculation indicated that the adsorption of AH at collophane was attributed to the chemical bonding. Moreover, AH molecule formed O-O five-membered ring with calcium ion on the collophane surface.

Keywords: *hydroxamic acid, collophane, dolomite, separation mechanism*

Introduction

Phosphorus, produced from phosphate ore, is an important raw material in agriculture industry (Santana et al., 2008). More than 95% of phosphate ore in the world is consumed in fertilizer industry (Santana et al., 2012). As the requirement of phosphate ore increases, high grade phosphate ore resources are exhausted. Thus, the depletion of the high grade phosphate ores attracts more attention to low grade phosphate beneficiation (Merma et al., 2013).

More than half of worldwide production of commercial phosphate is upgraded by flotation (Santana et al., 2011). The flotation technique for upgrading phosphate ore depends on the types of gangue minerals. For siliceous phosphate ore, reverse flotation technology is successfully used to separate silicate from phosphate with cationic

collector at neutral pH (Mohammadkhani et al., 2011; Boulos et al., 2014). However, the calcareous phosphate ore is not easy to purify by flotation because the physicochemical characteristic of carbonate and apatite surface is similar (Abouzeid et al., 2009).

According to numerous studies, flotation is still a dominant technology to separate carbonate from phosphate ore for calcareous phosphate (Ahmed et al., 2013). In the process, carbonate as a primary impurity is separated from phosphate using fatty acid or their ramification as collector. Meanwhile, apatite is depressed by depressants such as different acids, various organic and inorganic salts (Sis et al., 2003; Boulos et al., 2014). However, the reverse flotation for calcareous phosphate confronts some difficulties because optimal pH range is acidic (Al-Fariss et al., 2014). In this case, a portion of P_2O_5 is lost due to the dissolution of phosphate in acidic medium. Moreover, a large amount of calcium and magnesium ions in the pulp precipitates with collector molecule which results in the increase in collector consumption (Dos Santos et al., 2012).

Currently, the research orientations to solve this problem can be classified into two basic types: one is to exploit the efficient depressants that can be applied in neutral medium such as microorganism, which was utilized for enhancing the separation selectivity of minerals by modifying minerals surface characteristic (Elmahdy et al., 2013). The other one is to exploit high selectivity collectors such as chelating agents (Wang et al., 2006).

Hydroxamic acid has long been known as a high selectivity chelating agent for metal cations. Although hydroxamic acid was used as a collector for separating different valuable minerals from their gangues such as scheelite, cassiterite, and diasporite (Jiang et al., 2010; Wanget al., 2013; Zhao et al., 2013), the application of hydroxamic acid to separate colophane from dolomite still needs to be studied.

Therefore, the present work aims at studying the separation behavior and mechanism of colophane and dolomite using an efficient collector–alkyl hydroxamic acid (AH). The flotation performance of the AH was evaluated by micro-flotation experiments of pure mineral, artificially mixed sample and real phosphate ore. The mechanism of the AH adsorbed on mineral surfaces was interpreted by infrared spectra, zeta potential, adsorption, thermodynamics, and quantum chemical calculation.

Materials and methods

Materials

Colophane and dolomite samples used in this study were obtained from the Zhongxiang and Wuhan in the Hubei Province, China, respectively. The pure minerals were picked with the help of microscope, and ground to 90% $-74\mu\text{m}$ fraction in a ceramic ball mill. The specific surface areas of colophane and dolomite determined by the BET test are presented in Table 1. For the zeta potential measurement and FTIR

analysis, the samples were further ground to about $-2\mu\text{m}$. The results of chemical analysis showed that the P_2O_5 content of collophane was 38.66% and MgO content of dolomite was 19.70%. Additionally, the real phosphate ore was crushed and ground to 92% $-74\mu\text{m}$ fraction and the results of chemical analyses of the real phosphate ore are given in Table 2.

Table 1. Specific surface of collophane and dolomite

Particle Size (μm)	Weight (%)	Collophane (m^2/g)	Dolomite (m^2/g)
-74	90	1.632	2.853

Table 2. Chemical analysis results of phosphate ore (mass fraction, %)

Element	P_2O_5	MgO	Fe_2O_3	Al_2O_3	CaO	SiO_2	LOI	F
Content (%)	19.84	7.84	0.69	1.02	39.26	8.94	19.12	1.66

LOI – Loss on ignition

AH was used as a collector which was synthesized with coconut oil and hydroxylamine hydrochloride. HCl and NaOH of analytical grade from Kemiou Chemical Reagent Factory China were used to regulate the pH of the system. Distilled water was used in the experiments.

Methods

Flotation experiments

The micro-flotation tests of single mineral and artificially mixed samples were performed using a XFGC-80 flotation machine with a 50 cm^3 cell. Two grams of a mineral sample was placed in the cell which then was filled with distilled water. The suspension was agitated with a rotational speed of 1600 rpm. The pH was adjusted to a desired value with addition of HCl and NaOH solutions. Then, AH ($2 \cdot 10^{-5}\text{ mol}/\text{dm}^3$) was added into the cell with 3 min conditioning time. The froth and sink products were weighed and assayed respectively after the filtration and drying, and the results were used to calculate the recovery. The experimental error for the micro-flotation experiments was obtained by conducting five flotation tests, and statistical analysis of grade and recovery data. The experimental error was found to be 5~7%.

The flotation tests of phosphate ore (400 g) were conducted in an XFD-type laboratory flotation machine with 1.0 dm^3 cell. The air flow rate was $45\text{ dm}^3/\text{h}$ and the agitation speed was 1850 rpm. The conditioning time with collector (500 g/Mg) was 3 min. The froth and sink products were weighed and assayed respectively after the filtration and drying, and the results were used to calculate the recovery. The experiments were repeated three times, and the reported values are the average of the three experiments.

Zeta potential measurements

The zeta potentials of the minerals were measured using a Brookhaven Zeta Plus Zeta Potential Analyzer (manufactured in the USA). The concentration of the mineral suspension was 0.04 wt%, and the $1 \cdot 10^{-3}$ mol/dm³ NaCl solution was used as a background electrolyte. The measurements were conducted at room temperature 25 °C. The pH value of the suspension was adjusted to a desired value using HCl and NaOH solutions. Besides, further measurements also were carried out with the addition of AH at a constant concentration. The average zeta potential values of at least five independent measurements were recorded with a measurement error of ± 2 mV.

Adsorption experiments

In this research, the amount of collector adsorbed on the mineral surfaces was measured by the solution depletion method using a UV-VIS spectrophotometer (UV775B, China). An amount of 1.0 g of pure mineral sample was placed in the 250 cm³ conical flask. After adding 50 cm³ AH solution at a constant concentration ($2.62 \cdot 10^{-4}$ mol/dm³, $3.49 \cdot 10^{-4}$ mol/dm³, $4.37 \cdot 10^{-4}$ mol/dm³, $5.24 \cdot 10^{-4}$ mol/dm³, $6.11 \cdot 10^{-4}$ mol/dm³) into the suspension, the suspension was conditioned with the collector in the water-bathing constant temperature vibrator for 1 h. Then, the solid particles were separated by centrifuge for 12 min. The concentration of the collector in the supernatant was measured using UV-VIS spectrophotometer. The collector adsorption on the mineral surface was calculated by Eq. (1)

$$\Gamma = \frac{(C_0 - C)V}{mA} \quad (1)$$

where Γ is the amount (mol/m²) of the collector adsorbed at the mineral/aqueous solution interface, C_0 and C are the initial and supernatant concentrations (mol/dm³), respectively, m is the mass (g) of the mineral sample for each test, V is the volume (dm³) of the collector solution, and A is the specific surface area (m²/g) of the particle.

FTIR measurements

Fourier Transform Infrared (FTIR) spectra ranging from 4000 to 500 cm⁻¹ were used to characterize AH and the adsorption on the mineral surface at room temperature. The pure mineral samples were ground to -2 μ m and conditioned with the collectors ($1 \cdot 10^{-2}$ mol/dm³). The pellets were prepared by mixing KBr and mineral at the mass ratio of 200/1. The spectra of the samples were obtained with KBr pellets by a Fourier transform infrared spectrometer Nicolet.

Results and discussion

Characterization of AH

In order to investigate the characteristics of the new collector, the FTIR was used, and the infrared spectra of AH is shown in Fig. 1. The IR spectrum of AH contains intensive stretching vibration of O-H with peak frequencies at 3050 cm^{-1} and 3251 cm^{-1} . The peak frequencies at 2941 cm^{-1} and 2848 cm^{-1} arise from stretching vibration absorption of $-\text{CH}_2$. The bands found at 1622 cm^{-1} , 1661 cm^{-1} , and 1771 cm^{-1} come from stretching vibration absorption of $\text{C}=\text{N}$ and $\text{C}=\text{O}$ in the collector molecule. The characteristics peaks appearing at 1424 cm^{-1} and 1436 cm^{-1} are bending vibration of $-\text{CH}_3$ and $-\text{CH}_2$, respectively. The stretching vibration absorption of $\text{N}-\text{O}$ was observed at 968 cm^{-1} and 1017 cm^{-1} . Therefore, it can be concluded that the new synthesized collector contains the characteristics absorption peaks of alkyl hydroxamic acid.

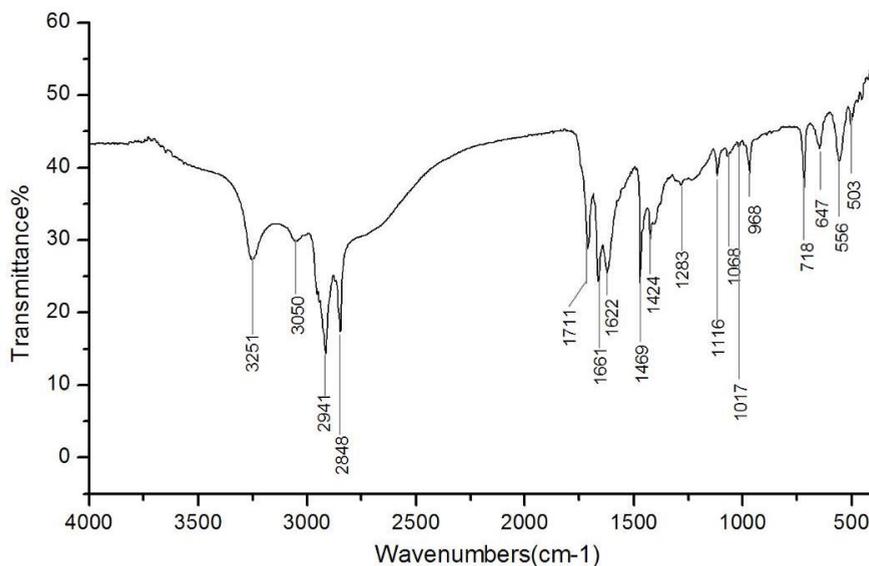


Fig. 1. FTIR spectra of AH

Flotation performance of single minerals

Figure 2 presents the flotation results of collophanite and dolomite with AH as a function of the pulp pH value. The experiments were performed at the concentration of $\text{AH} = 2 \cdot 10^{-5}\text{ mol/dm}^3$ at room temperature ($25\text{ }^\circ\text{C}$). It was observed that AH showed very good selectivity for collophanite over a wide range of pH value. The floatability difference of two minerals was obvious at the pH range between 3 and 10, and the maximum flotation recovery was obtained in the neutral medium. Additionally, when the pH was changed to 2, the flotation recovery of collophane decreased, which was due to the presence of calcium ions dissolved from collophane. The calcium ions form

water-insoluble precipitates with AH, a process that normally results in flotation values decrease (Nanthakumaret al., 2009). Therefore, it is important to control the concentration of calcium ions when AH is used as collector in the flotation process.

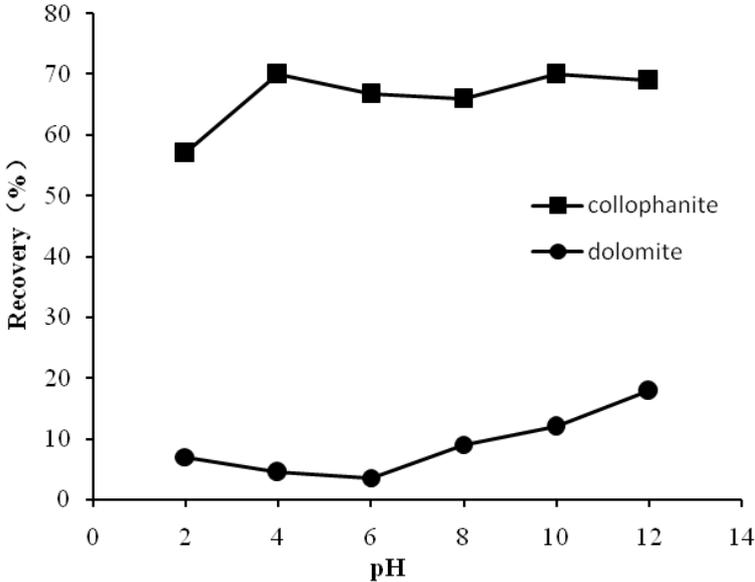


Fig. 2. Flotation results of collophanite and dolomite as a function of pH

Flotation separation of artificially mixed sample

The results of single mineral flotation tests showed that AH had a remarkable selectivity for the separating collophanite from dolomite in neutral medium. In order to further investigate the separation performance, the flotation tests on the artificially mixed sample were conducted. The artificially mixed sample was prepared by the mixing two single minerals at the mass ratio of 3/1, namely, the mixture contained 75% collophanite. Figure 3 presents the flotation results of artificially mixed sample as a function of pH value. The results indicated that the P_2O_5 grade of the concentrate increased slightly with the increase of the pH when the pH value was less than 6. After that, the P_2O_5 grade of the concentrate decreased, and the maximum value of P_2O_5 grade (32.26%) was obtained when the pH value was about 6. In addition, the P_2O_5 recovery of the concentrate reached 96.94% at maximum when the pH value was about 8. By considering the relationship between the grade and recovery, the products with 31.85% P_2O_5 grade and 94.56% P_2O_5 recovery can be obtained when the pH value was about 7.

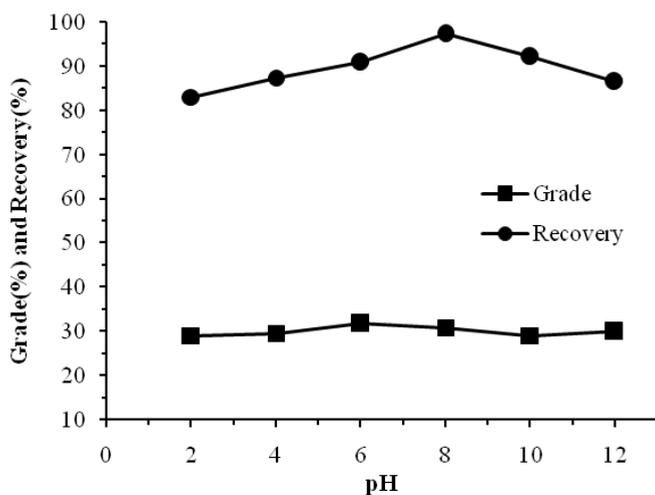


Fig. 3. Flotation results of artificial mixture as a function of pH value

Flotation performance of real ore

Figure 4 provides a flotation separation performance of the real phosphate ore obtained under different operating conditions using AH as a collector. The results showed that the P_2O_5 recovery of the concentrate decreased significantly with the P_2O_5 grade of concentrate increase. The P_2O_5 grade of concentrate was increased from 19.84% to 30.51% when the P_2O_5 recovery of concentrate decreased from 100% to 79.16%, which achieved the target grade ($\beta P_2O_5 \geq 30\%$).

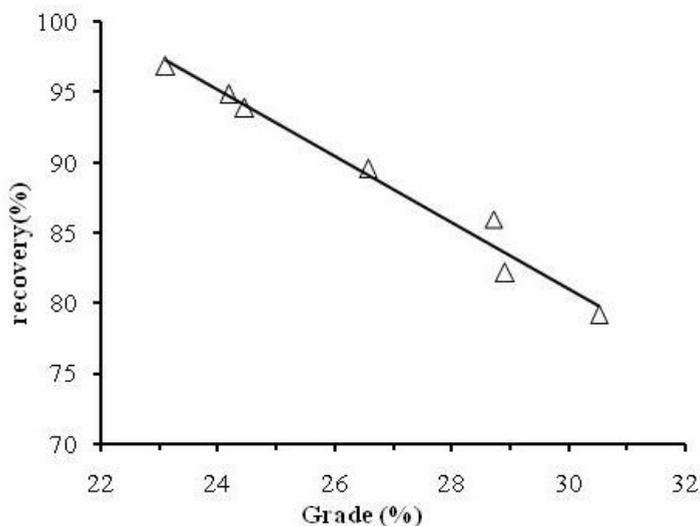


Fig. 4. Flotation results of real ore

Zeta potential measurements

The zeta potential results of collophanite in distilled water and AH solutions at different pH values are given in Fig. 5a. The zeta potential of collophanite in water was negative and decreased with the increase of the pH. Additionally, it was not possible to obtain the isoelectric point (IEP) value of collophanite. Nevertheless, IEP values of apatite between 2.0 and 8.0 are reported in the literature (Merma et al., 2013). This collophanite behavior could be explained due to its tolerance to isomorphous substitutions regardless of its origin and composition, which alter the IEP value of the mineral (Merma et al., 2013). Figure 5a also shows the zeta potential profile of the collophanite after the interaction with AH over the studied pH range. The addition of AH leads to a decrease in the zeta potential of collophanite. Moreover, the change was more pronounced at pH range between 6 and 7. It indicated that the AH molecules were adsorbed on the mineral surface.

As shown in Fig. 5b, the zeta potential of dolomite in water decreased with the increase of the pH, and the IEP of dolomite was about 4.0. Furthermore, it can be seen that the IEP of dolomite changed from 4.0 to around 3.4 in the presence of AH solution. The slight variation indicated that the amount of AH adsorbed on the dolomite surface in the aqueous AH solution was small.

Comparing the zeta potential results for two minerals, the variation of absolute value of the zeta potential for collophanite and dolomite in AH solutions as a function of pH is shown in Fig. 6. The zeta potential variation of dolomite is more significant than collophanite over the pH range between 2 and 4, which is probably because of the dissolution of the dolomite in the acidic medium. As the pH increased, the variation absolute value of zeta potential for collophanite increased and surpassed the dolomite (Fig. 6). It can be concluded that the amount of AH adsorbed on collophanite surface is more than dolomite under the same conditions, which is the essential reason that use of AH facilities separation of collophanite and dolomite.

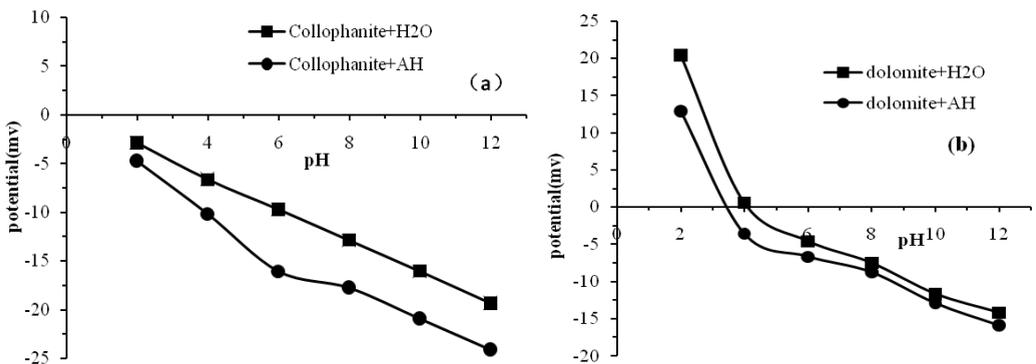


Fig. 5. Zeta potential of (a) collophanite (b) dolomite in distilled water and AH solution as a function of pH

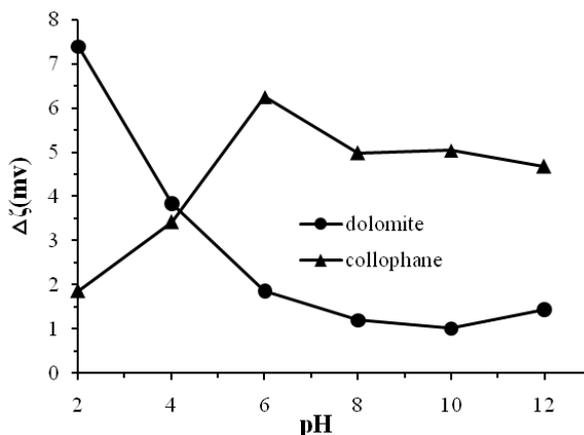


Fig. 6. Variation of absolute value of zeta potential for collophanite and dolomite in AH solution as a function of pH

FTIR analysis

In order to investigate the adsorption mechanism of AH on the mineral surfaces, the raw minerals and minerals reacting with AH were characterized by the infrared spectrometry.

The FTIR spectrum of dolomite before and after reacting with AH is shown in Fig. 7a. After the interaction with AH, the stretching vibration peaks at 1661 cm^{-1} and 1622 cm^{-1} of C=N could be observed on dolomite surface although they were weak. The characteristics peaks at 2956 cm^{-1} , 2921 cm^{-1} and 2851 cm^{-1} arise from stretching vibration of $-\text{CH}_3$ and $-\text{CH}_2$ respectively. This shows that a surface compound formed on dolomite.

Figure 7b displays the infrared spectra of collophane before and after reacting with AH. In contrast with the spectra A, the infrared spectra of collophane surface reacting with AH appears obvious characteristics peaks at 3439 cm^{-1} , 2921 cm^{-1} , 2851 cm^{-1} , 1771 cm^{-1} , 1661 cm^{-1} and 1622 cm^{-1} . The peak frequency at 3439 cm^{-1} comes from stretching vibration of O-H in H_2O molecule adsorbed on collophane surface. The characteristics peaks at 2921 cm^{-1} and 2851 cm^{-1} arise from stretching vibration of $-\text{CH}_2$. Additionally, there exists C=N and C=O stretching vibration at 1771 cm^{-1} , 1661 cm^{-1} and 1622 cm^{-1} . It can be concluded that there exists stable chemical compound on the collophane surface.

A comparison of infrared spectra of collophane and dolomite interaction with AH revealed that the characteristics peaks of C=N, $-\text{CH}_3$ and $-\text{CH}_2$ on collophane were stronger than those on dolomite. This indicates that the amount of AH adsorbed on collophane surface is greater than that on dolomite, which is in good agreement with the results of collector adsorption experiments (Figs. 8 and 9).

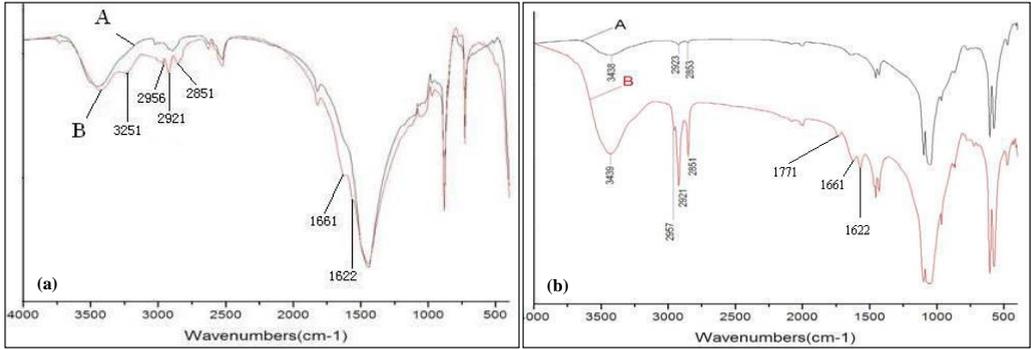


Fig. 7. FTIR spectra of (a) dolomite(b) collophane before (A) and after (B) reacting with AH

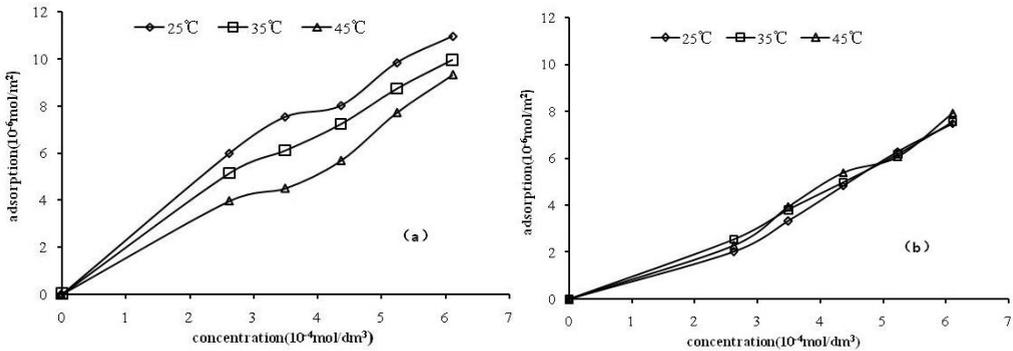


Fig. 8. Adsorption isotherms of AH on (a) collophane(b) dolomite surfaces at different temperatures

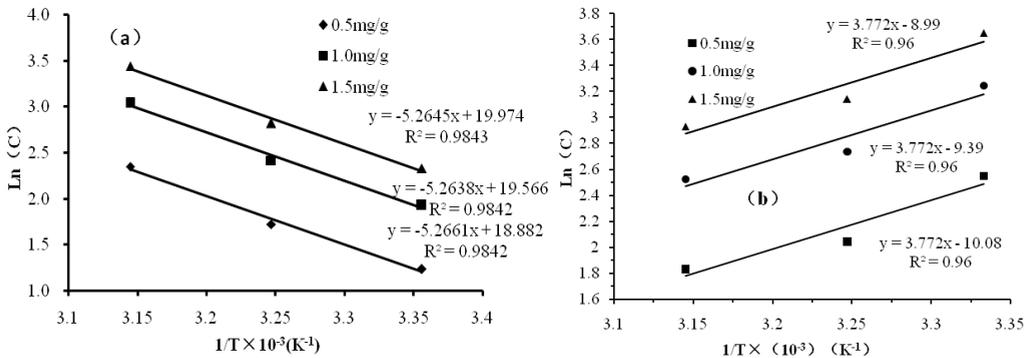


Fig. 9. Fitting curves of equivalent adsorption on (a) collophane (b) dolomite at three different levels

Adsorption experiments

The adsorption measurements of AH on the surface of collophane and dolomite as a function of AH concentration were performed in neutral medium (pH = 6.8). Figure 8 shows the adsorption isotherms of AH on collophane and dolomite surfaces at three different temperatures, respectively. The results indicated that the adsorption quantity

of AH on the mineral surface increased with the increasing concentration of AH for both minerals. Under the condition of room temperature, the adsorption quantity on the collophane surface was higher than that on the dolomite surface at the low concentration of AH solution. This is also verified by the results of the zeta potential measurement (see Fig. 5). For collophane, the adsorption quantity of AH decreased with the increasing temperature because the AH molecules at high temperature showed higher free energy which made them more likely to desorb from the mineral surface. Meanwhile, the free AH molecules were not easy to adsorb on the mineral surfaces due to the high kinetic energy. The situation for dolomite was opposite since the adsorption quantity of AH showed a slight increase with the increase of the temperature. Thus, AH chelating collector can be used to separate collophane from dolomite at a low collector dosage at room temperature in the direct flotation of calcareous phosphate ore.

Thermodynamic calculation

The enthalpy change (ΔH) of adsorption can be calculated using Eq. 2 (Geet et al., 2014):

$$\ln C = \frac{\Delta H}{RT} + \text{constant} \quad (2)$$

where C is the concentration of AH solution, R is constant, T temperature in kelvin, ΔH adsorption enthalpy.

The thermodynamic parameters of AH adsorption for collophane are listed in Table 3. Figure 9a shows the fitting curves of the equivalent adsorption on collophane at three different adsorption levels in term of parameters presented in Table 3. The enthalpy changes (ΔH) of adsorption were calculated as follows:

when $\Gamma = 0.5$ mg/g, the slope of curve (K1) is equal to $-5.266 \cdot 10^3$ (Fig. 9a):

$$\Delta H_{(\Gamma=0.5 \text{ mg/g})} = -5.2661 \cdot 10^3 \times R = -5.2661 \cdot 10^3 \times 8.3145 = -43.79 \text{ kJ/mol}$$

when $\Gamma = 1.0$ mg/g:

$$\Delta H_{(\Gamma=1.0 \text{ mg/g})} = -5.2638 \cdot 10^3 \times R = -5.2638 \cdot 10^3 \times 8.3145 = -43.766 \text{ kJ/mol}$$

when $\Gamma = 1.5$ mg/g:

$$\Delta H_{(\Gamma=1.5 \text{ mg/g})} = -5.2646 \cdot 10^3 \times R = -5.2646 \cdot 10^3 \times 8.3145 = -43.77 \text{ kJ/mol.}$$

According to the calculation results, the enthalpy changes (ΔH) of the adsorption at three different adsorption levels are greater than 40 kJ/mol. It is believed that the adsorption process of AH is held on the surface of collophane by chemical bond. Meanwhile, the adsorption process is an exothermic reaction because the enthalpy changes of adsorption are negative.

The calculation method of enthalpy changes (ΔH) of AH adsorbed on dolomite is the same as that on collophane. The thermodynamic parameters are listed in Table 3. The fitting curves of equivalent adsorption on dolomite at three different adsorption levels are given in Fig. 9b. The enthalpy changes (ΔH) of adsorption were calculated as follows:

when $\Gamma = 0.5 \text{ mg/g}$, $K1=3.77026 \cdot 10^3$ (Fig. 9b):

$$\Delta H_{(\Gamma=0.5 \text{ mg/g})} = 3.772 \cdot 10^3 \times R = 3.772 \cdot 10^3 \times 8.3145 = 31.35 \text{ kJ/mol}$$

when $\Gamma = 1.0 \text{ mg/g}$:

$$\Delta H_{(\Gamma=1.0 \text{ mg/g})} = 3.772 \cdot 10^3 \times R = 3.772 \cdot 10^3 \times 8.3145 = 31.35 \text{ kJ/mol}$$

when $\Gamma = 1.5 \text{ mg/g}$:

$$\Delta H_{(\Gamma=1.5 \text{ mg/g})} = 3.772 \cdot 10^3 \times R = 3.772 \cdot 10^3 \times 8.3145 = 31.35 \text{ kJ/mol.}$$

The enthalpy changes (ΔH) of adsorption at three different adsorption levels are less than 40 kJ/mol. According to literature (Zhu and Zhu, 1993), the enthalpy change of physisorption is less than 9 kJ/mol, and chemisorption is larger than 40 kJ/mol. Therefore, there exists physisorption and chemisorption when AH is adsorbed on the dolomite surface. In addition, the adsorption process is an endothermic reaction which explains that the adsorption quantity of AH on dolomite surface has a slight increase with the increase in temperature (see Fig. 8).

Based on the results of the thermodynamic calculation for both minerals, it can be concluded that the adsorption behavior of AH on collophane is enhanced while the temperature decreases because the adsorption process is an exothermic reaction. However, the situation for dolomite is opposite since the adsorption process is endothermic. Therefore, the effect of separating collophane from dolomite with alkyl hydroxamic acid at room temperature is better than that at high temperature.

Table 3. Thermodynamic parameters of adsorption of AH on the collophane and dolomite surfaces in aqueous solution

	Γ (mg/g)	C (mg/dm ³)			Ln C			1/T (K ⁻¹)
		298 K	308 K	318 K	298 K	308 K	318 K	
Collophane	0.5	3.44	5.61	10.47	1.24	1.72	2.35	0.003356
	1.0	6.88	11.22	20.93	1.93	2.42	3.04	0.003247
	1.5	10.32	16.83	31.40	2.33	2.82	3.45	0.003145
Dolomite	0.5	12.83	7.73	6.25	2.551786	2.045109	1.832581	0.003333
	1.0	25.66	15.46	18.46	3.244933	2.738256	2.525729	0.003247
	1.5	38.49	23.19	27.69	3.650398	3.143721	2.931194	0.003145

Quantum chemical calculation

The optimized molecule models of two types of alkyl hydroxamic acid are presented in Fig. 10. Some selected atomic charges were calculated, and the results are presented in Table 4. The results indicate that the atomic charges of 39O and 42O are higher than other atoms in both types of AH molecules. It can be concluded that 39O and 42O atoms are easy to offer their electrons to calcium and magnesium ions on the collophane and dolomite surfaces to form ionic bond (Liu et al., 2015).

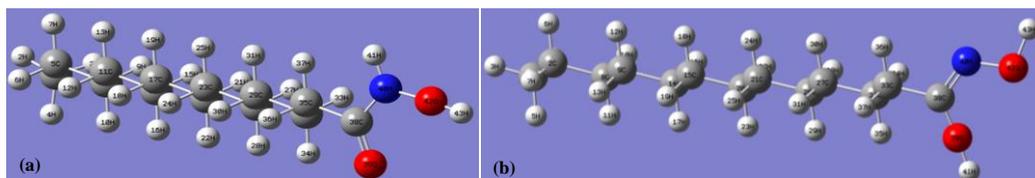


Fig. 10. Molecule model of alkylhydroxamic acid(a) AH^{-1} (b) AH^{-2}

Table 4. Selected Mulliken atomic charges of AH^{-1} and AH^{-2}

Reagent	Mulliken atomic charges
AH^{-1}	40N: -0.226683; 39O: -0.415645; 42O: -0.701150; 38C: 0.551314
AH^{-2}	40N: -0.183200; 39O: -0.709937; 42O: -0.497207; 38C: 0.544746

Figure 11 shows the schematic diagram of alkyl hydroxamic acid adsorbed on the collophane and dolomite surfaces in aqueous environment. It was also observed that two types of AH molecules form O-O five-membered ring with calcium and magnesium ions on the collophane and dolomite surfaces, respectively.

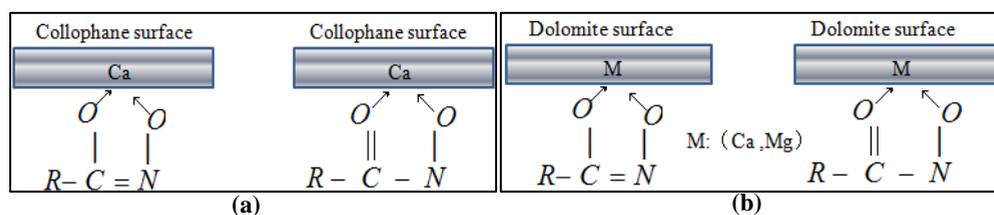


Fig. 11. Schematic diagrams of alkylhydroxamic acid adsorbed on (a) collophane (b) dolomite surfaces in aqueous solution

Conclusions

Alkylhydroxamic acid exhibits selective collection of collophane coexisting with dolomite, allowing preferential flotation separation in neutral medium. The results of artificially mixed minerals and real phosphate ore separation show that AH can separate collophane from dolomite without any other reagents, and the concentrate

with 30.51% P₂O₅ grade and 79.16% P₂O₅ recovery can be obtained when the pH value is about 7.

Collophane has a more obvious variation of zeta potential than dolomite in AH solution when pH value is greater than 4, indicating a stronger interaction with AH. The FTIR spectra show the presence of AH on the surface of collophane, meanwhile, AH is preferably adsorb on the surface of collophane by chemical bond. The spectrum of dolomite reacting with AH is nearly similar with dolomite. Due to adsorption test and thermodynamic calculation, there exist several different adsorption behaviors between collophane and dolomite: (1) adsorbed collector density of collophane decreases significantly with the increase of temperature, while that of dolomite has a slight increase; (2) adsorbed collector density of collophane is larger than that of dolomite with low collector dosage at room temperature; (3) the process of AH adsorption on collophane is an exothermic reaction, while the situation for dolomite is opposite. Quantum chemical calculation results show that AH adsorbs onto collophane surface by chemical adsorption, which the AH molecule form O-O five-membered ring with calcium ion on the collophane surface.

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